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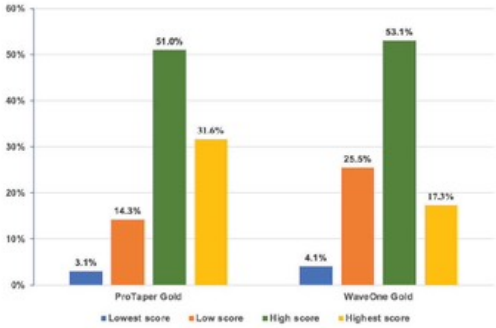

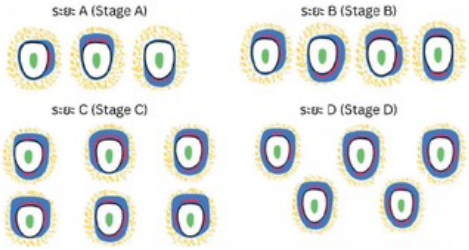

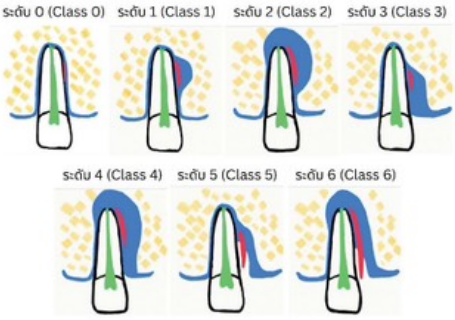

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▶ Original article ◀

Evaluating Sixth-Year Dental Students' Performance and Preference Using NiTi Rotary Systems: A Comparative Analysis of ProTaper Gold and WaveOne Gold in Educational Settings

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Abstract

Objective: Nickel-titanium (NiTi) rotary systems, such as ProTaper Gold (PTG) and WaveOne Gold (WOG), are widely used for root canal shaping due to their flexibility. PTG operates in continuous rotation, whereas WOG uses reciprocation, potentially influencing their suitability for inexperienced operators. This retrospective cohort study compared the performance and preferences of PTG and WOG on molars among sixth-year dental students during their first experience with rotary endodontics.

Materials and Methods: Requirement books records and corresponding radiographs of extracted permanent molars prepared by sixth-year dental students in a rotary laboratory course were reviewed. Each student prepared one maxillary and one mandibular molar using either PTG or WOG, with the sequence varied across four groups. Root canal preparation quality was evaluated using predefined criteria for procedural errors, including inadequate master apical file (MAF) size or length, loss of apical stop, ledging, canal deviation, zipping, perforation, and instrument separation. Records were verified by endodontic staff and cross-checked radiographically by calibrated examiners. Students also completed a questionnaire evaluating their perceptions of the two systems. Data were analysed using McNemar's and Wilcoxon signed-rank tests for procedural errors, and the Wilcoxon signed-rank test for student preferences.

Results: No significant differences were observed in procedural error rates between PTG (82.7%) and WOG (88.8%), with inadequate MAF length being the most common error for both systems. Students rated PTG significantly higher in controllability, with 61.2% preferring it over WOG. PTG was preferred for its superior controllability, ease of root canal filling, and higher screwing effect, whereas WOG was favoured for shorter instrumentation time and satisfactory controllability.

Conclusion: Both PTG and WOG systems demonstrated similar performance in procedural error rates during root canal preparation by novice operators in a preclinical setting. However, most students preferred PTG, citing its superior controllability, ease of obturation, and enhanced screwing effect.

Keywords: dental education, nickel-titanium rotary system, procedural error, root canal preparation, student preference.

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Introduction

Nickel-titanium (NiTi) rotary instruments have gained popularity over traditional stainless-steel hand instruments due to their advantages in root canal shaping, comprising greater flexibility and shorter preparation times (1). These instruments preserve the original root canal curvature, thereby reducing procedural errors for less experienced operators such as undergraduate dental students (2-4). However, a significant drawback is an increase in instrument separation, which poses challenges in undergraduate education where students may lack the experience necessary to manage such complications (4, 5). Therefore, an ideal NiTi rotary system for students should be safe, effective, easy to use, and affordable while minimizing the risk of errors or complications (6).

Several modern NiTi rotary systems have been introduced with varying design philosophies, metallurgy, and kinematics to enhance safety and efficacy. Among these, the ProTaper Gold and WaveOne Gold (PTG and WOG; Dentsply Sirona, Ballaigues, Switzerland) are two modern systems featuring advanced gold wire technology to improve flexibility and cyclic fatigue resistance, potentially reducing the risk of instrument separation during root canal preparation (7). Despite these shared metallurgical advancements, the PTG and WOG systems differ significantly in their design and operating principles, which may influence their ease of use and procedural outcomes for inexperienced operators (8, 9).

The PTG system uses continuous rotation with a convex triangular cross-section, blunt tip, and variable taper, whereas the WOG system employs reciprocating motion with an offset parallelogram cross-section, two cutting edges, semi-active tip, and regressive taper. Such differing kinematics represent distinct approaches to root canal shaping. Continuous rotation provides smooth and efficient canal cutting (10) but may increase the screwing effect and risk of instrument separation (11, 12). Conversely, reciprocation reduces torsional stress and enhances safety but may require a steeper learning curve for new users (6, 12). These differences highlight the need to evaluate their performance among dental students with no prior NiTi rotary experience.

Most previous studies comparing PTG and WOG systems focus on experienced operators, particularly regarding canal transportation and centring ability. However, the results remain inconclusive regarding which system performs better in canal shaping (13, 14). In addition, several studies have reported no instrument separation in either system (15, 16). Notably, no study has investigated the performance of these systems when used by inexperienced operators, including dental students, particularly concerning procedural errors and user preferences. This lack of research causes uncertainty about the preferred system for undergraduates to provide the safest, most effective, and satisfactory experience during root canal preparation.

In this study, we aimed to compare the performance of the PTG and WOG systems on molars by evaluating procedural errors and student preferences among sixth-year dental students who had prior completed hand instrumentation practices and used these rotary systems for the first time in a preclinical laboratory setting.

Materials and Methods

This retrospective cohort study protocol was approved by the Institutional Review Board of the Faculty of Dentistry and Faculty of Pharmacy, Mahidol University, Bangkok, Thailand (MU-DT/PY-IRB 2023/044.1810).

Study subjects

Data were obtained from requirement books, which included working length (WL), master apical file (MAF) size, and procedural errors noted by the instructor, radiographs (original, WL, and MAF) and questionnaires filled by sixth-year dental students who attended a rotary endodontics laboratory course at the Faculty of Dentistry, Mahidol University, Thailand in 2022. Only cases with high-quality radiographs and complete records of requirement books and questionnaires were included to ensure accurate analysis. Cases involving separate hand instruments, inability to achieve apical patency and to determine a proper working length, or those in which the initial apical file (IAF) exceeded the available rotary file size were excluded.

Rotary endodontics laboratory course

This course was conducted on extracted human first or second permanent molars with closed apices. Maxillary molars had three roots, and mandibular molars had two, with tooth lengths ranging from 17 to 23 mm. Teeth with root resorption, root caries, calcification, and prior endodontic treatment were excluded. Root canal curvature did not exceed 30° using Schneider's method (17). Preoperative radiographs were obtained in buccal-lingual and mesial-distal views using Kodak RVG 6500 CMOS sensors (Kodak RVG 6500, Carestream Health, NY, USA). Selected teeth were mounted on a full-arch acrylic model to simulate an operation in a manikin's oral cavity. Subsequently, an original radiograph was obtained.

All participant students had completed prior hand instrumentation in both the laboratory (4th year) and the clinic (5th year), but had no experience with NiTi rotary systems. A total of 109 students and 218 selected molars—109 maxillary and 109 mandibular—were randomly allocated into four groups using stratified randomisation based on hand-instrumentation canal preparation scores and root canal curvature. Students were stratified into high- and low-score subgroups according to the median of their fourth-year laboratory and fifth-year clinical MI scores. Molars were stratified by canal curvature as straight (≤10°), moderate (>10° to ≤20°), and severe (>20° to ≤30°) using Schneider's method (17). Following stratification, students and molars were randomly assigned to four groups, each classified based on exposure to both PTG and WOG systems, alternating between maxillary and mandibular molars as follows: Mx-PTG/Md-WOG (Maxillary molar with PTG, followed by mandibular molar with WOG); Md-PTG/Mx-WOG (mandibular molar with PTG, followed by maxillary molar with WOG); Mx-WOG/Md-PTG (maxillary molar with WOG, followed by mandibular molar with PTG); Md-WOG/Mx-PTG (mandibular molar with WOG, followed by maxillary molar with PTG).

An instructor provided a theoretical introduction and instructions on the root canal preparation protocol using ProGlider and both rotary systems before the procedures (Fig. 1). Each set of NiTi rotary files was used on two molars. The procedures were performed by the students under the supervision of the endodontic department staff in

each designated laboratory zone. The MAF size was gauged using a NiTi hand file, and a periapical radiograph of the prepared canals was taken in a standardised manner at the same angle as the preoperative images, following completion of root canal preparation. The MAF size, MAF length and all procedural errors were recorded in the requirement book by the supervising endodontic staff. Root canals were obturated through the lateral compaction technique using standardised 0.02 tapered gutta-percha cones and a zinc oxide eugenol-based sealer (MU sealer, M dent, Mahidol University, Thailand). Final radiographs were obtained to confirm the completeness of the root canal treatment.

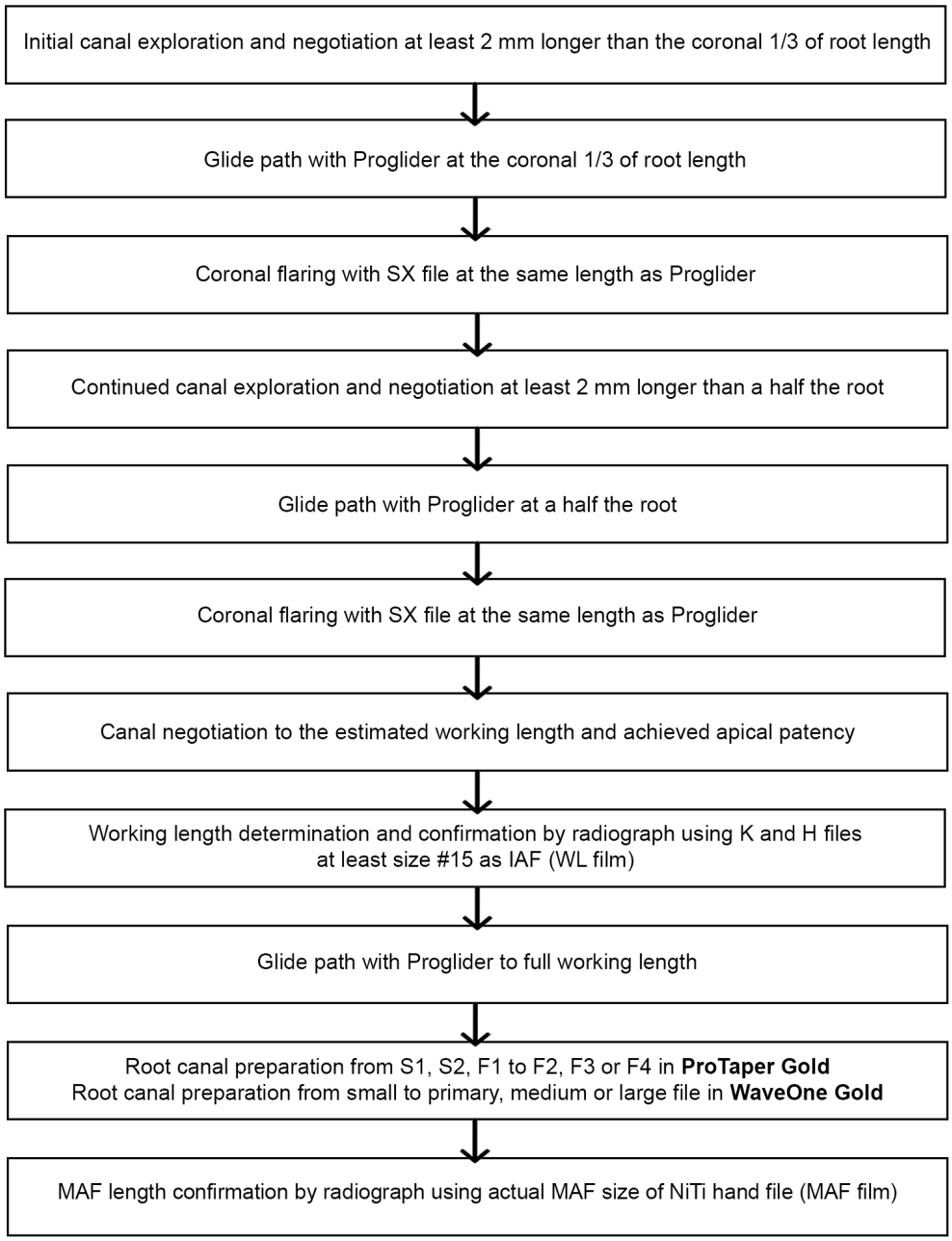

Figure 1 Root canal preparation protocol for ProGlider, ProTaper Gold, and WaveOne Gold used in this endodontic laboratory course.

Subsequently, students completed a questionnaire evaluating their experiences with PTG and WOG systems following the practical course (Fig. 2). The questionnaire covered eight categories, including ease to learn, screwing effect sensation, screwing effect preference, feeling controllable, cutting efficiency, instrumentation time, ease of filling the root canal (FRC), and overall satisfaction. Students rated each category on a 4-point scale (1= lowest score, 4 = highest score). Finally, they were asked to select their preferred NiTi rotary system and provide the reasons.

Questionnaire of sixth-year students' preferences on NiTi rotary systems

Instructions: Please select one answer for each question by circling the number that best represents your opinion.

Part 1: Level of satisfaction on ProTaper Gold® and WaveOne Gold®

Questionnaires	ProTaper Gold®				WaveOne Gold®			
	Highest	High	Low	Lowest	Highest	High	Low	Lowest
1. Ease to learn	4 The instrument was very easy to learn.	3	2	1 The instrument was very difficult to learn.	4 The instrument was very easy to learn.	3	2	1 The instrument was very difficult to learn.
2. Screwing effect sensation	4 The instrument was greatly pulled into the root canal apically.	3	2	1 The instrument was not pulled or required pressure into the root canal apically.	4 The instrument was greatly pulled into the root canal apically.	3	2	1 The instrument was not pulled or required pressure into the root canal apically.
3. Screwing effect preference	4 I was very satisfied with the instrument being pulled into the root canal apically.	3	2	1 I was very unsatisfied with the instrument being pulled into the root canal apically.	4 I was very satisfied with the instrument being pulled into the root canal apically.	3	2	1 I was very unsatisfied with the instrument being pulled into the root canal apically.
4. Feeling controllable	4 I felt very easy to control the instrument.	3	2	1 I felt very difficult to control the instrument.	4 I felt very easy to control the instrument.	3	2	1 I felt very difficult to control the instrument.
5. Flexibility	4 The instrument was very flexible and could follow the curvature of the root canal very well.	3	2	1 The instrument was not flexible and could not follow the curvature of the root canal.	4 The instrument was very flexible and could follow the curvature of the root canal very well.	3	2	1 The instrument was not flexible and could not follow the curvature of the root canal
6. Cutting effect	4 The instrument could cut the dentin very well.	3	2	1 The instrument could not cut the dentin.	4 The instrument could cut the dentin very well	3	2	1 The instrument could not cut the dentin.
7. Instrumentation time	4 The instrument required the least instrumentation time.	3	2	1 The instrument required the most instrumentation time.	4 The instrument required the least instrumentation time.	3	2	1 The instrument required the most instrumentation time.
8. Overall satisfaction	4 Very satisfied/ I definitely chose to use the instrument.	3 Satisfied/ I chose to use the instrument, but I tried using other NiTi rotary systems before.	2 Unsatisfied/ I could use the instrument.	1 Very unsatisfied / I did not want to use the instrument anymore.	4 Very satisfied/ I definitely chose to use the instrument.	3 Satisfied/ I chose to use the instrument, but I tried using other NiTi rotary systems before.	2 Unsatisfied/ I could use the instrument.	1 Very unsatisfied / I did not want to use the instrument anymore.

Part 2: Which NiTi rotary system do you prefer to use?

☐ ProTaper Gold® ☐ WaveOne Gold®

Please specify the reasons

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.....

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Figure 2 The questionnaire form used in this endodontic laboratory course.

Data acquisition and outcome assessment

Part 1: Root canal preparation quality

Data on the MAF size, MAF length and procedural errors were obtained from requirement books, recorded by supervising endodontic staff, and confirmed with radiographs. The radiographs were interpreted by two examiners who were blinded to the study groups. The examiners were trained by a board-certified endodontist before the analysis. Intra- and inter-examiner reliability was measured using Cohen's Kappa between 0.81 to 0.99, indicating an almost perfect agreement (18). Disagreements were resolved through consensus discussion.

Procedural errors were assessed by comparing the canal status before and after mechanical instrumentation and were recorded as frequencies according to predefined criteria, as follows: Inadequate MAF size was identified when the actual MAF size at the working length was smaller or larger than the expected size. Inadequate MAF length was identified when the MAF with the expected size was positioned shorter or longer than the working length. Loss of apical stop was identified when the MAF with the expected size advanced beyond the working length. Ledging was identified when a visible step was present on the canal wall. Canal deviation was identified when the MAF deviated toward the inside or outside of the root canal curvature compared to the original canal path. Zipping was identified when the apical foramen appeared elliptical or teardrop-shaped. Perforations were categorised as apical, strip, or lateral based on their location. Finally, the separated instruments were identified when the rotary instrument fractured within the root canal or extended beyond the periapical area.

Each molar can be subjected to multiple procedural errors and the total potential errors vary following the number of root canals. Consequently, the total errors for each tooth were calculated as a percentage, using a denominator determined by multiplying the number of root canals by the 10 possible error types. For example, if a tooth had three root canals, the denominator used to calculate the percentage of procedural errors was 30.

Part 2: Student preferences

Data were acquired from the answered questionnaires and recorded as frequencies according to the scores in each perception category. Finally, the preferred NiTi rotary system and the reasons for its preference were summarised.

Statistical analysis

Data were analysed using the SPSS version.22 (SPSS Inc., Chicago, IL, USA) and STATA version.17 (StataCorp., Texas College Station, TX, USA). The statistical significance was set at $p < 0.05$. We compared the presence of procedural errors between the PTG and WOG groups using McNemar's test. The Wilcoxon signed-rank test was used to compare the percentage of total errors for each tooth between the two instrument groups.

The possible factors contributing to the errors, including the NiTi rotary system, students' hand instrument scores, tooth location, tooth side, tooth length, root canal curvature, and the working sequence of each file system during root canal preparation, were analysed using generalised estimating equations (GEE). The logistic regression model assessed the influence of various factors on the presence of specific procedural errors, whereas the linear regression model identified the factors

that contributed to total errors in each tooth. Initial potential factors ($p \leq 0.01$ in the univariate analysis) were further analysed in the multivariate analysis.

The Wilcoxon signed-rank test was used to compare the PTG and WOG groups across each perception category for student preferences. The reasons for selecting the NiTi rotary system are summarised below.

Results

Ninety-eight of 109 sixth-year dental students who met the eligibility criteria were included in this study. Students were excluded based on predefined criteria: four molars had hand instrument separation, apical patency could not be achieved in four molars, three molars had an initial apical file (IAF) size exceeding the available NiTi rotary files, and one student had incomplete documentation. There were no significant differences in the overall data from the distribution of the molars treated with the PTG and WOG systems ($p > 0.05$), except on the tooth side (Table 1). Specifically, the WOG group had a higher number of right molars (60.2%) than the PTG group (39.8%). In contrast, the PTG group had more left molars (56.1%) than the WOG group (43.9%). This variation on the tooth side was statistically significant ($p = 0.029$). The overall teeth characteristics were balanced between the groups; however, the tooth-side variation suggested potential variation in root canal preparation.

Table 1 Data distribution of root canal preparation using each instrument (n = 98) on molars.

Factors	PTG n (%)	WOG n (%)	*p*-value
Tooth location			0.686
Maxillary molars	47 (48.0)	51 (52.0)	
Mandibular molars	51 (52.0)	47 (48.0)	
Tooth side			0.029*
Right	43 (43.9)	59 (60.2)	
Left	55 (56.1)	39 (39.8)	
Tooth length (mm)			0.396
Short, ≤20	64 (65.3)	58 (59.2)	
Long, >20	34 (34.7)	40 (40.8)	
(mean ± SD)†	19.87 ± 1.22	20.03 ± 1.35	0.387
Root canal curvature (degree) ‡			0.947
Straight, ≤10°	2 (2.0)	1 (1.0)	
Moderate, >10°, ≤20°	44 (44.9)	45 (45.9)	
Severe, >20°, ≤30°	52 (53.1)	52 (53.1)	
(mean ± SD)†	20.60 ± 4.87	20.30 ± 4.88	0.677

Statistical analysis was performed by McNemar test, except † was performed by paired t-test and ‡ was performed by random-effects ordered logistic regression.

* Statistically significant difference ($p < 0.05$)

Procedural errors

Procedural errors were classified into inadequate MAF size, inadequate MAF length, and other errors (Table 2). Representative radiographs are shown in Fig. 3. Errors were observed in the PTG and WOG groups (82.7 and 88.8%, 81/98 and 87/98 molars, respectively). The commonest error was inadequate MAF length, occurring in 76.5 and 78.6% of the PTG- and the WOG-treated molars, respectively. The median percentage of errors per tooth was 13.3 and 10% in the PTG and WOG, respectively. Nevertheless, statistical analysis revealed that the type of NiTi rotary system (PTG vs. WOG) did not significantly affect the presence, type, or total number per tooth of procedural errors ($p > 0.05$).

Table 2 Procedural errors using each instrument (n = 98) on molars

Procedural errors	PTG n (%)	WOG n (%)	*p*-value
Inadequate MAF size	56 (57.1)	56 (57.1)	1.000
Smaller than expected size	2 (2)	1 (1)	
Larger than expected size	51 (52)	55 (56.1)	
Both	3 (3.1)	0 (0)	
Inadequate MAF length	75 (76.5)	77 (78.6)	0.871
Shorter than WL	31 (31.6)	40 (40.8)	
Longer than WL	26 (26.5)	20 (20.4)	
Both	18 (18.4)	17 (17.4)	
Loss of apical stop at WL	43 (43.9)	38 (38.8)	0.446
Ledging	10 (10.2)	6 (6.1)	0.424
Canal deviation	13 (13.3)	12 (12.2)	1.000
Zipping	3 (3.1)	2 (2)	1.000
Apical perforation	18 (18.4)	22 (22.5)	0.433
Strip perforation	0 (0)	1 (1)	1.000
Lateral perforation	0 (0)	0 (0)	N/A
Separated instrument	0 (0)	0 (0)	N/A
Presence of procedural errors	81 (82.7)	87 (88.8)	0.327
%Total errors in each tooth: median (Q1-Q3)†	13.3 (6.7-20)	10 (6.7-16.7)	0.704

Statistical analysis was performed by McNemar test, except † was performed by Wilcoxon signed-rank test.

* Statistically significant difference ($p < 0.05$)

N/A: not applicable

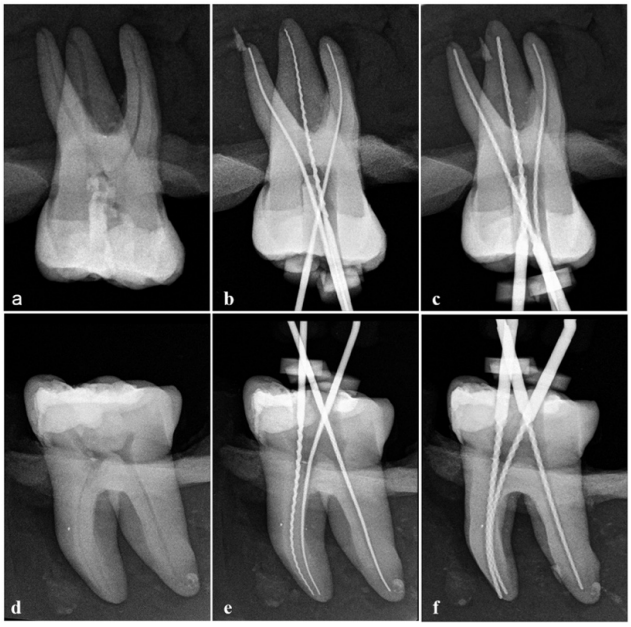

Figure 3 Representative radiographs illustrating procedural errors in molars. **(a–c: original, working length, and master apical file images)** – Maxillary molar: inadequate MAF length in the mesiobuccal (right) canal; inadequate MAF length and canal deviation in the palatal (middle) canal. **(d–f: original, working length, and master apical file images)** – Mandibular molar: inadequate MAF length and apical perforation in the mesiolingual (left) canal; inadequate MAF length in the distal (right) canal.

The key factors contributing to procedural errors were identified through further analysis. Students with higher proficiency in hand instruments generally had significantly fewer errors (Table 3; Odds ratio [OR] = 0.52, p = 0.018), particularly inadequate MAF lengths (Table 4; OR = 0.47, p < 0.001). These students experienced fewer incidences of both MAF being shorter and longer than the working length (25.5 vs. 37.6% and 18.4 vs. 23.2%, respectively). In addition, the severity of the root canal curvature and tooth side were significant predictors of canal deviation (Table 5) and apical perforation (Table 6). Severe canal curvature (OR = 6.66, p = 0.013) and left molars (OR = 2.18, p = 0.047) increased the risk of canal deviation, while moderate curvature was associated with a lower risk of apical perforation (OR = 0.49, p = 0.045).

Table 3 GEE logistic regression model of factors associated with procedural errors.

Factors	Univariable		Multivariable	
	Odds ratio (95% CI)	*p*-value	Odds ratio (95% CI)	*p*-value
NiTi rotary system				
PTG vs WOG	1.12 (0.78-1.61)	0.527		
Students' hand instrument score				
Low vs High	0.52 (0.30-0.89)	**0.016**	0.52 (0.30-0.89)	**0.018***
Tooth location				
Maxillary molars vs Mandibular molars	0.96 (0.67-1.39)	0.838		
Tooth side				
Right vs Left	1.22 (0.82-1.81)	0.328		
Tooth length (mm)				
Short, ≤20 vs Long, >20	0.95 (0.65-1.39)	0.790		
Root canal curvature (degree)				
Straight, ≤10°	1			
Moderate, >10°, ≤20°	0.86 (0.54-1.38)	0.526		
Severe, >20°, ≤30°	0.90 (0.53-1.51)	0.684		
Working sequence of each file system in root canal preparation				
First vs Second	1.40 (0.98-2.01)	**0.067**	1.40 (0.97-2.03)	0.070

* Statistically significant difference ($p < 0.05$)

Table 4 GEE logistic regression model of factors associated with inadequate MAF length.

Factors	Univariable		Multivariable	
	Odds ratio (95% CI)	*p*-value	Odds ratio (95% CI)	*p*-value
NiTi rotary system				
PTG vs WOG	1.09 (0.77-1.56)	0.617		
Students' hand instrument score				
Low vs High	0.47 (0.31-0.70)	**<0.001**	0.47 (0.31-0.70)	**<0.001***
Tooth location				
Maxillary molars vs Mandibular molars	0.99 (0.69-1.43)	0.970		
Tooth side				
Right vs Left	1.11 (0.78-1.59)	0.555		

Table 4 GEE logistic regression model of factors associated with inadequate MAF length. (continued)

Factors	Univariable		Multivariable	
	Odds ratio (95% CI)	*p*-value	Odds ratio (95% CI)	*p*-value
Tooth length (mm)				
Short, ≤20 vs Long, >20	0.95 (0.65-1.39)	0.790		
Root canal curvature (degree)				
Straight, ≤10°	1			
Moderate, >10°, ≤20°	0.97 (0.62-1.51)	0.879		
Severe, >20°, ≤30°	1.14 (0.69-1.88)	0.599		
Working sequence of each file system in root canal preparation				
First vs Second	1.02 (0.72-1.46)	0.893		

* Statistically significant difference ($p < 0.05$)

Table 5 GEE logistic regression model of factors associated with canal deviation.

Factors	Univariable		Multivariable	
	Odds ratio (95% CI)	*p*-value	Odds ratio (95% CI)	*p*-value
NiTi rotary system				
PTG vs WOG	0.70 (0.34-1.46)	0.343		
Students' hand instrument score				
Low vs High	0.66 (0.30-1.48)	0.315		
Tooth location				
Maxillary molars vs Mandibular molars	0.81 (0.38-1.72)	0.587		
Tooth side				
Right vs Left	2.09 (0.97-4.51)	**0.061**	2.18 (1.01-4.69)	**0.047***
Tooth length (mm)				
Short, ≤20 vs Long, >20	0.97 (0.47-2.03)	0.938		
Root canal curvature (degree)				
Straight, ≤10°	1			
Moderate, >10°, ≤20°	3.68 (0.83-16.27)	**0.086**	3.98 (0.89-17.71)	0.070
Severe, >20°, ≤30°	6.18 (1.38-27.62)	**0.017**	6.66 (1.48-29.99)	**0.013***
Working sequence of each file system in root canal preparation				
First vs Second	1.61 (0.77-3.37)	0.209		

* Statistically significant difference ($p < 0.05$)

Table 6 GEE logistic regression model of factors associated with apical perforation.

Factors	Univariable		Multivariable	
	Odds ratio (95% CI)	*p*-value	Odds ratio (95% CI)	*p*-value
NiTi rotary system				
PTG vs WOG	1.31 (0.75-2.28)	0.345		
Students' hand instrument score				
Low vs High	0.66 (0.31-1.41)	0.285		
Tooth location				
Maxillary molars vs Mandibular molars	0.91 (0.52-1.59)	0.730		
Tooth side				
Right vs Left	0.90 (0.48-1.68)	0.737		
Tooth length (mm)				
Short, ≤20 vs Long, >20	0.71 (0.39-1.31)	0.278		
Root canal curvature (degree)				
Straight, ≤10°	1			
Moderate, >10°, ≤20°	0.49 (0.24-0.98)	**0.045**	0.49 (0.24-0.98)	**0.045***
Severe, >20°, ≤30°	0.78 (0.38-1.60)	0.499		
Working sequence of each file system in root canal preparation				
First vs Second	1.05 (0.61-1.83)	0.851		

* Statistically significant difference ($p < 0.05$)

Student preferences

Student preferences was evaluated using questionnaires, and 98 students provided feedback on both systems. Both systems were rated highly by most students across various categories; however, the WOG system received lower scores for the screwing effect preference. Overall, the PTG system had higher satisfaction, and 32.7% of students were assigned the highest score, compared to 26.5% for the WOG system. Furthermore, the PTG system performed better regarding perceived controllability and received the highest score from 31.6% of the students, compared to 17.4% for WOG ($p = 0.009$). No significant differences were observed in the other categories or overall satisfaction between the two systems ($p > 0.05$) (Table 7 and Fig. 4).

Sixty students (61.2%) favoured the PTG system, whereas 38 students (38.8%) preferred the WOG system when asked to choose their preferred system. Students who preferred the PTG system cited reasons comprising superior controllability (20 students), ease of root canal filling using lateral compaction (15 students), and a preference for the screwing effect sensation (11 students). They indicated that the PTG system allowed smoother root canal preparation, enhanced tactile sensation with continuous rotation, better maintenance of the apical stop, and increased confidence in following the root canal path. In addition, they discovered that the PTG system facilitated obturation, thereby creating more space and tapering the canal.

Table 7 Students' preference of each instrument (n = 98) based on each perception category.

Questionnaires	PTG				WOG				*p*-value
	4	3	2	1	4	3	2	1	
Ease to learn	45 (45.9)	52 (53.1)	1 (1.0)	0 (0)	50 (51.0)	46 (46.9)	2 (2.0)	0 (0)	0.480
Screwing effect sensation	27 (27.6)	45 (45.9)	21 (21.4)	5 (5.1)	23 (23.5)	46 (46.9)	25 (25.5)	4 (4.1)	0.601
Screwing effect preference	23 (23.5)	45 (45.9)	24 (24.5)	6 (6.1)	21 (21.4)	33 (33.7)	35 (35.7)	9 (9.2)	0.059
Feeling controllable	31 (31.6)	50 (51.0)	14 (14.3)	3 (3.1)	17 (17.4)	52 (53.1)	25 (25.5)	4 (4.1)	**0.009***
Cutting efficiency	38 (38.8)	53 (54.1)	7 (7.1)	0 (0)	38 (38.8)	53 (54.1)	7 (7.1)	0 (0)	0.971
Instrumentation time	39 (39.8)	38 (38.8)	19 (19.4)	2 (2.0)	45 (45.9)	45 (45.9)	7 (7.1)	1 (1.0)	0.051
Ease of FRC	23 (23.5)	45 (45.9)	26 (26.5)	4 (4.1)	16 (16.3)	47 (48.0)	27 (27.6)	8 (8.2)	0.014
Overall satisfaction	32 (32.7)	51 (52.0)	15 (15.3)	0 (0)	26 (26.5)	46 (46.9)	26 (26.5)	0 (0)	0.082

Statistical analysis was performed by the Wilcoxon signed-rank test.

* Statistically significant difference ($p < 0.05$)

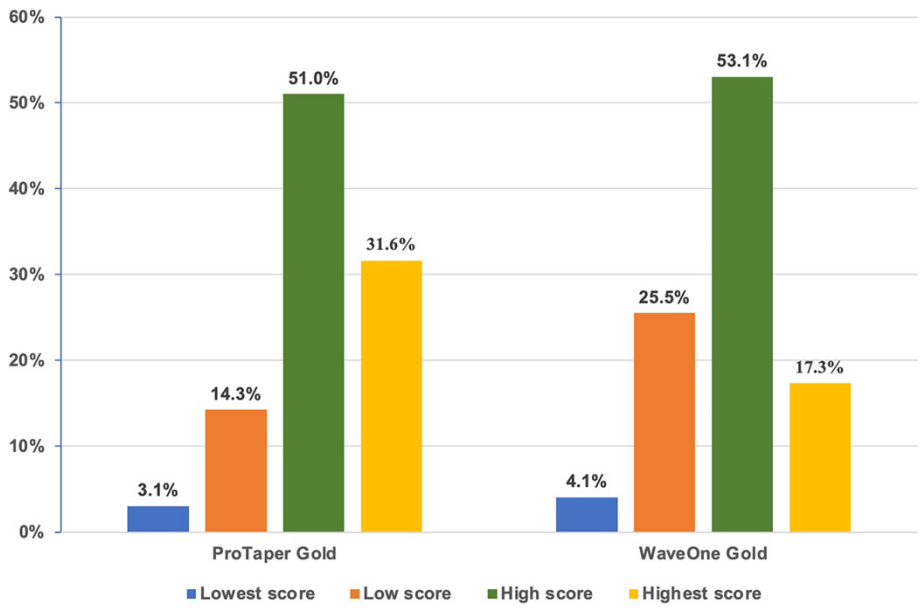

Figure 4 Score distributions for ProTaper Gold and WaveOne Gold in the perception category of feeling controllable. Score 1 = lowest; 2 = low; 3 = high; 4 = highest score.

In contrast, students who preferred the WOG system emphasised shorter instrumentation time (18 students) and greater controllability (16 students). The WOG system required fewer steps and used fewer files for root canal enlargement, and its motor does not require adjustments during file changes, thereby reducing the overall instrumentation time. Furthermore, the reduced screwing effect sensation of the WOG system, which allowed for greater control and precision when stopping at the working length and preserving the apical stop, was preferred.

In summary, the PTG system is generally preferred due to its controllability, ease of root canal filling, and higher screwing effect. In contrast, the WOG system is favoured because of its shorter instrumentation time and controllability.

Discussion

Studies comparing NiTi instrument systems have demonstrated their suitability for inexperienced operators, particularly regarding mechanical performance and user satisfaction (9, 19). To address this gap, we compared the performance and preference of PTG and WOG among first-time sixth-year dental students during a rotary endodontic laboratory course. This course simulated clinical conditions using extracted molars, which provided a realistic tactile sensation of dental hard tissue rather than standardised resin blocks, offering a more authentic experience. Although the use of extracted molars introduced challenges in standardising tooth characteristics, the distribution of these characteristics was balanced across students using both systems, except for the tooth side (Table 1). While three-dimensional imaging technologies have advanced, 2D radiography remains a common clinical tool due to its accessibility and cost-effectiveness (20), despite its limitations in detecting certain procedural errors such as MAF size, loss of apical stop, or ledging (21, 22). In this study, procedural errors were identified using recorded requirements and radiographic confirmation, and were analysed by calibrated examiners for accuracy and reliability. In addition, a questionnaire was administered to assess student preferences between the two rotary systems, providing simple and effective subjective data, and was completed by the students immediately after use to offer fresh insights into their perceptions (19).

The analysis revealed no significant difference in the incidence of procedural errors between the PTG and WOG systems, which is consistent with studies involving experienced operators (15). Prior research mainly focused on canal transportation and centring ability, which produced conflicting results that depended on the methodology, tooth samples, and operator experience (13, 14). In this study, we focused on novice users and their ability to perform root canal preparations without significant procedural errors.

Inadequate MAF length was the most common procedural error, occurring in 76.5% of PTG and 78.6% of PTG and WOG cases, respectively. In addition, it was shorter than the working length in 31.6 and 40.8% of PTG and WOG cases, respectively. This is often due to unstable coronal reference points or errors such as ledging and canal deviation, impeding the instrument from reaching its working length. This result aligns with that of previous studies showing that inexperienced operators often struggle to achieve precise apical preparation (23). Furthermore, loss of apical stop occurred in PTG

and WOG cases (43.9 and 38.8%, respectively), further highlighting the challenges that inexperienced students face in maintaining working length stability.

Notably, another error was the inadequate MAF size, which was present in 57.1% of cases, with the majority larger than expected in 52 and 56.1% of the PTG and the WOG cases, respectively. This is potentially caused by excessive instrumentation or holding the instrument at the working length for an extended period. This finding may offer a new perspective on the challenges faced by inexperienced operators, as no previous studies have compared the MAF sizes across these systems.

Other procedural errors were rare in both systems. This could be attributed to factors including the selection of low-to-moderate-difficult cases (24), adherence to step-by-step instructions, limiting each instrument to two molars before discarding, and the use of advanced gold-wire instruments that enhance flexibility and reduce canal deviation (25). Despite no occurrence of instrument separation during canal preparation, one SX file separated during coronal flaring. This aligns with previous research indicating a higher separation rate for instruments with continuous motion than for those with reciprocating motion (26).

Factors contributing to the quality of root canal preparation included student proficiency with hand instruments, canal curvature, and tooth side. All participating students in this laboratory course had prior hand instrumentation experience to enhance their manual dexterity and understanding of root canal anatomy, both of which are essential when transitioning to NiTi rotary systems. Although such training does not guarantee improved rotary performance (27), our study indicated that students with higher hand instrumentation scores made fewer errors. This finding underscores the important role of manual dexterity in mastering rotary instrumentation by enabling effective instrument control and careful procedural execution (28). In addition to student proficiency, canal curvature influenced errors. Canals with severe curvature (>20°, ≤30°) were prone to canal deviation, consistent with previous findings that curved canals are more challenging to navigate (15), as instruments tend to straighten within curved canals, leading to dentine overcutting on the outer wall (29). Additionally, moderately curved canals (>10°, ≤20°) had a lower chance of apical perforation. Straight canals (≤10°), although easier to prepare, are more susceptible to apical perforation, likely due to less resistance toward the apical foramen (30, 31). In severely curved canals, apical perforation is often the most severe consequence of errors, such as canal transportation (32). The final factor was the tooth side, with the left molars being more susceptible to canal deviation. This can be attributed to their further position, leading to challenging accessibility and difficult instrument control.

Regarding user preference, most students preferred the PTG system (61.2%), citing controllability as their main reason. They favoured the smoother preparation and enhanced tactile feedback provided by the continuous rotation of PTG, which helped them achieve the desired MAF size while preserving the apical stop. In contrast, the reciprocating motion of the WOG system generated more vibrations, which may have diminished the students' sense of control, despite reducing the screwing effect sensation (6).

This study had some limitations, including difficulty in detecting certain errors using 2D radiographs, inherent variability of tooth characteristics, absence of a hand instrumentation control group, and the lack of consideration for factors such as students' manual dexterity. Objective measures, such as the time required for root canal shaping, would enhance the reliability of subjective factors. Further research, particularly randomised controlled trials and the clinical impact of error severity on treatment outcomes, is warranted to validate these findings. Nonetheless, this study provided valuable insights into the use of NiTi rotary systems by novice operators and offers potential improvements for endodontic education.

Conclusion

Within the limitations of this study, both the PTG and WOG systems demonstrated comparable procedural error rates in root canal preparation on molars performed by inexperienced operators. However, specific errors such as inadequate MAF length, canal deviation, and apical perforation were associated with factors including students' hand instrumentation skills, the degree of root canal curvature, and the tooth side.

Regarding student preferences, PTG scored significantly higher than WOG in perceived controllability, although there were no significant differences in overall satisfaction. Most students preferred PTG due to its superior controllability, ease of obturation using lateral compaction, and enhanced screwing effect.

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